National Aeronautics and
Space Administration

Washington, D C
20546



Reply to Attn of GP-4

TO: NIT-44/Scientific and Technical Information Division
Attn: Shirley Peigare

FROM: GP-4/Office of Assistant General Counsel
for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP-4 and Code NST-44, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 4,407,563

Issue Date : Oct. 4, 1983

Government or
Contractor Employee: U.S. Gov't

NASA Case No. : GSC-12,683-1

NOTE - If this patent covers an invention made by a contractor employee under a NASA contract, the following is applicable:

YES / / NO /X/

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the specification, following the words "...with respect to an invention of...."

(NASA-Case-GSC-12683-1) HIGH SPEED MULTI FOCAL PLANE OPTICAL SYSTEM Patent (NASA) 6 p CSCL 20F

N83-36898

Unclas
00/74 11237

25th Anniversary
1958-1983

GC 12,683-1

United States Patent [19]

Minott

[11] **4,407,563**

[45] **Oct. 4, 1983**

[54] **HIGH SPEED MULTI FOCAL PLANE OPTICAL SYSTEM**

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[73] Assignee: **The United States of America as represented by the United States National Aeronautics and Space Administration**, Washington, D.C.

[21] Appl. No: **333,535**

[22] Filed **Dec. 22, 1981**

[51] **Int. Cl.**[3] **G02B 27/10**; G02B 17/08

[52] **U.S. Cl.** **350/173**; 350/445

[58] **Field of Search** 350/173, 171, 169, 172, 350/174, 170, 445, 286, 287

[56] **References Cited**

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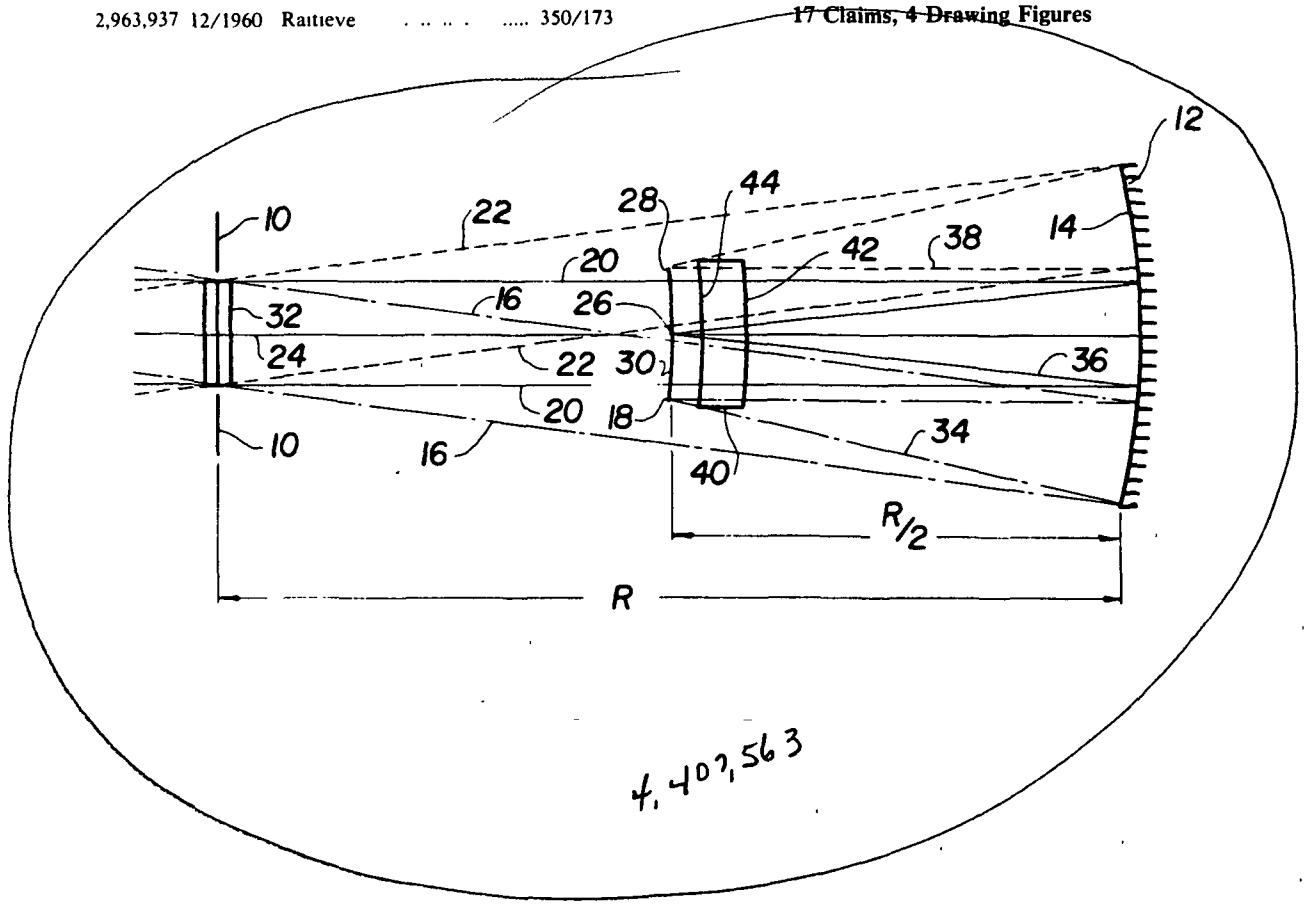
Primary Examiner—Jon W. Henry

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[57] **ABSTRACT**

Apparatus for eliminating beamsplitter generated optical aberrations in a pupil concentric optical system providing a plurality of spatially separated images on different focal planes or surfaces (**30, 56**) The system employs a buried surface beamsplitter (**40, 40'**) having spherically curved entrance (**42**) and exit faces (**44, 54, 74, 76**) which are concentric to a system aperture stop (**10**) with the entrance face being located in the path of a converging light beam (**34**) directed thereto from an image forming objective element (**12**) which is also concentric to the aperture stop.

17 Claims, 4 Drawing Figures



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FIG.1A

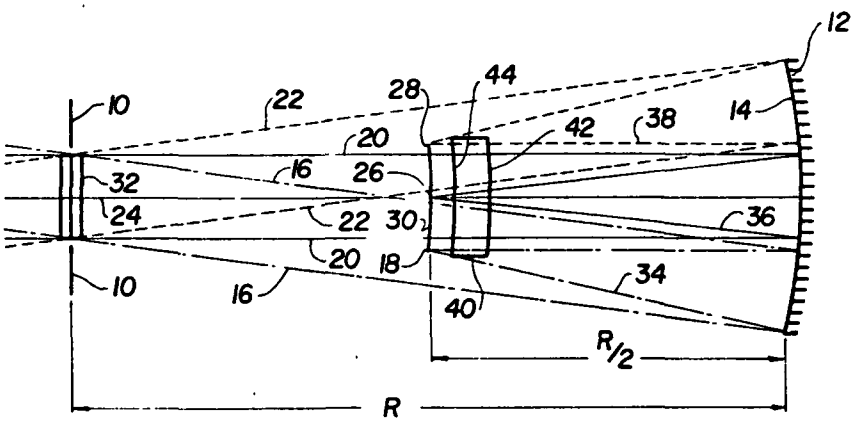


FIG.1B

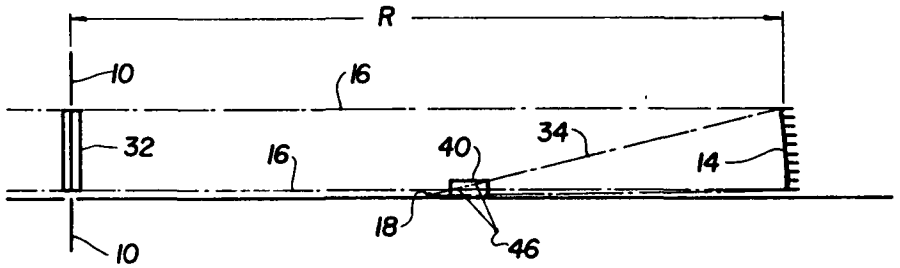
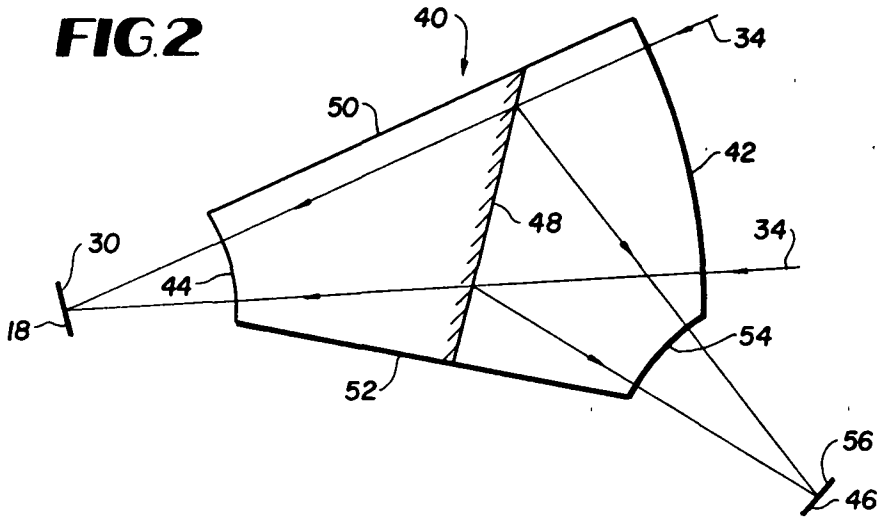


FIG.2



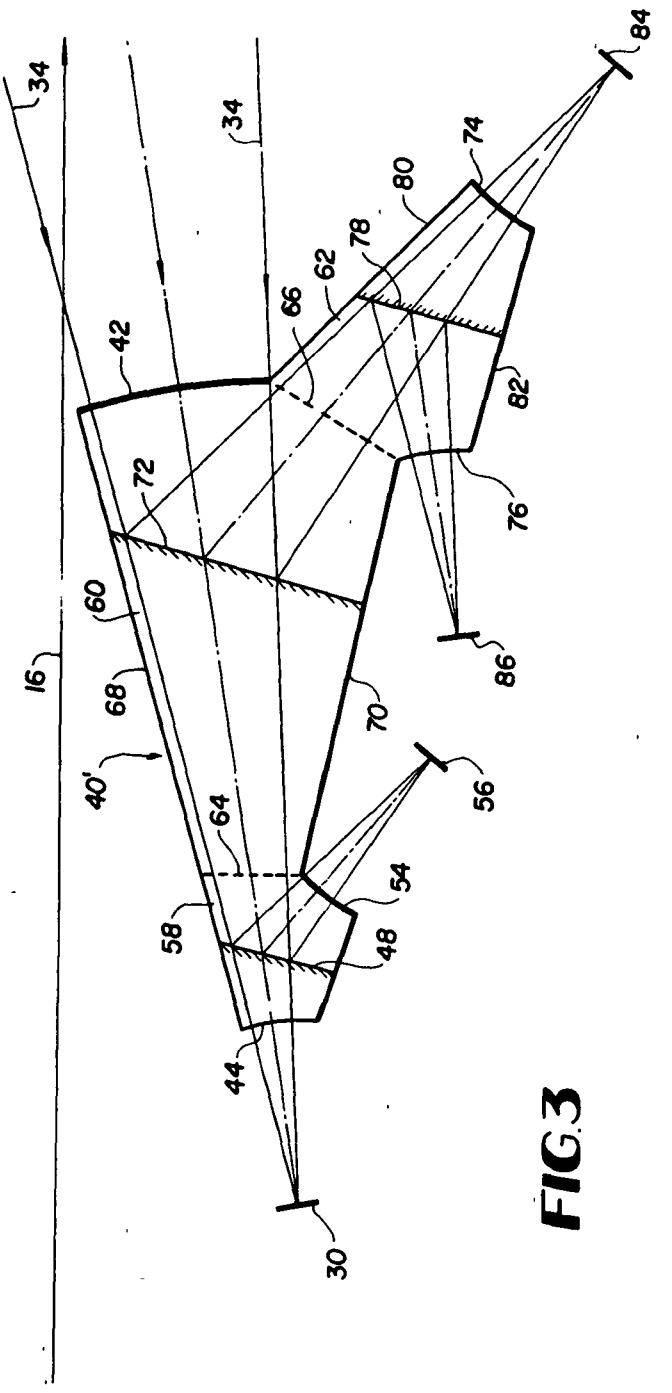

34
34
84
74
80
78
62
66
42
82
72
76
60
86
16
68
70
40'
64
56
54
58
48
44
30

FIG.3

HIGH SPEED MULTI FOCAL PLANE OPTICAL SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

TECHNICAL FIELD

The invention relates generally to optical imaging systems and more particularly to pupil concentric optical systems

BACKGROUND ART

There are many optical applications where it is desirable to have one optical objective form several images on different focal planes so that several separate detectors may view the same scene element. Examples of such applications are color TV cameras which use three vidicon tubes to record the scene in three colors and photographic cameras used in converting a color scene into three color images for color printing presses. Another application of particular importance is with respect to multi-spectral linear array mapping cameras which include several linear arrays of detectors located in the focal plane of a lens situated, for example, in an orbiting satellite. If the several linear arrays are parallel and if the direction of motion of the satellite is perpendicular to the arrays, a swath type of image will be generated as each array is swept across the earth in what is known as a pushbroom scan mode. Since the several linear arrays are not coincident, each array will see a point on the earth at a different delayed time. This time delay causes problems if the satellite rolls, pitches or yaws in an unpredictable manner between the passage of the several arrays. Accordingly, it becomes impossible to superimpose data of the arrays in a simple time delay process for generating an image. Also, if there is field dependent distortion in the objective, it is difficult to reconstruct the image without complicated computer models of the distortion. Further, if the scene on earth is viewed obliquely, it is extremely difficult to reconstruct the scene due to the fact that each detector array sees the scene at a slightly different angle.

For these reasons, it is normally desirable to place a selected number of beam splitters behind an objective lens and divide the output of the lens into several beams of light, each of which impinges on its own focal plane. This process shares the energy from the lens among the several focal planes, but uses only one common objective lens and permits all the linear arrays to be conjugate to a common line to the scene of view.

A serious limitation of this apparently simple solution exists when a plate or block type beamsplitter is placed in a converging ray light beam due to the fact that extremely undesirable optical aberrations are produced by the beamsplitter. These aberrations are of the well known chromatic and Seidel type. These aberrations can be compensated for when a block type beamsplitter is used if compensating aberrations are built into the lens, such as by designing opposite sign aberrations into the image forming section of the systems so that the sum of the compensating aberrations and the beamsplitting aberrations equals zero. However, the compensation process requires several additional optical elements and if the objective is large compared to the detector array, the complexity and cost of the components may be extremely high. Further, if the system is of a large aperture type, i.e. on the order of several feet in diameter, refractive elements can become prohibitively heavy requiring use, for example, of a reflective objective. Furthermore, with a reflective objective, a problem of eliminating aberrations becomes even more difficult because the designer has relatively little freedom to compensate for the chromatic aberrations in the beamsplitters.

One known method of eliminating beamsplitter aberrations is through use of pellicle type beamsplitters incorporating microscopically thin membranes stretched over a frame and coated with an evaporated beamsplitter layer. While pellicles effectively eliminate the optical problems, they are extremely fragile and are very prone to vibrations in a noisy environment. Another known method includes the use of a two element relay lens designed so that the rays are collimated between the elements. Beamsplitters are located between the two relay lens elements in the collimated region. Since the rays are not converging, no aberrations occur. The disadvantage of this method is that for each split, two reimaging lenses and one collimating lens must be used. Further, the problem of designing the relay lens becomes more difficult than that of designing the original objective if wide fields of view are required.

STATEMENT OF THE INVENTION

Accordingly, it is an object of the present invention to provide an improved optical system which is relatively free of distortion.

Another object of the invention is to provide a high resolution optical system adapted to provide multiple focal planes.

Still another object of the invention is to provide an inherently wide field optical system of a relatively simple construction with beamsplitters which do not add new types of aberrations to the system.

These and other objects are provided by a pupil concentric system including an aperture stop, at least one image forming element and a buried surface beamsplitter situated in the path of the converging light beam. The beamsplitter has an entrance face and at least two exit faces from which images emerge with the entrance and exit faces of the beamsplitter being curved and optically concentric to the aperture stop whereby beamsplitter generated aberrations are eliminated.

The foregoing as well as other objects, features and advantages of the invention will become apparent from the following detailed description when taken in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B are top plan and side elevational views, respectively, of a simple pupil concentric optical system embodying the subject invention;

FIG. 2 is a side elevational view of a two way beamsplitter for use in accordance with the teachings of the subject invention; and

FIG. 3 is a side elevational view of a four way beamsplitter for use in connection with the subject invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings wherein like numerals refer to like parts, FIGS. 1A and 1B illustrate a single reflector system typically representative of the well known Schmidt type of pupil concentric system. The system includes an aperture stop or pupil **10** which is located a radius distance R from a spherical reflector element **12**. The reflector element **12** is concentric with the aperture stop **10** and has a spherically curved concave reflecting surface **14** which is adapted to converge an incident light beam **16** (FIG. **1B**) to focal point **18**. Furthermore, as shown in FIG. **1A**, any additional incident beams represented by, for example the rays **20** and **22** which are directed respectively along the axis **24** and to the left thereof, they will converge at the focal points **26** and **28** which lie along a focal surface **30** which includes the focal point **18** The focal surface **30**, moreover, is located a distance approximately R/2 from the single concentric reflector **12**. In order to compensate for coma, astigmatism and spherical aberration, one or more corrector plates **32** of known construction are located at the aperture stop **10**. The apparatus thus far is of a conventional nature, however, if one were to utilize a cube type beamsplitter in the path of the converging beams **34**, **36** and **38** as shown in FIG. **1A**, severe Seidel and chromatic aberrations would be generated and it is to this problem that the present invention is directed.

A beamsplitter **40** of a specific construction is positioned in the path of the converging beam or beams reflected from the spherically curved face **14** of the reflector **12**. This beamsplitter **40** has entrance and exit faces which are spherically curved and concentric, optically at least, to the aperture stop **10**. As shown in FIG. **1A**, beamsplitter **40** is an optical element which forms an image on focal surface **30**. It has a convex entrance face **42** and a concave exit face **44**. The entrance face **42**, moreover, has a curvature which matches the spherical curvature of the reflector **12** so as to maintain light beams perpendicular to the entrance face for all parts of the field of view. The beamsplitter **40**, moreover, is a buried surface beamsplitter having an interior partially reflective surface, not shown, for producing a folded-back image at a focal point **46** shown in FIG **1B**. As will be shown, the exit face for producing the image at the focal point **46** is made to be optically concentric with the aperture stop **10**. Such a configuration will result in eliminating any aberrations which would otherwise be generated by the beamsplitter itself.

Referring now to FIG. **2**, shown therein is one type of buried surface beamsplitter **40** consisting of a pentagonal element including a partially reflective interior (buried) surface **48** angularly disposed between the spherically curved entrance face **42** and a forward spherically curved exit face **44**. In addition to two elongated side faces **50** and **52**, a rear spherically curved exit face **54** is formed between the curved entrance face **42** and the side wall **52**. The rear exit face **54**, moreover, is formed as a folded-back version of the forward exit face **44** with the fold being along the partially reflective surface **48**. This, in effect, makes the exit faces **44** and **54** optically coincident By making the entrance face **42** and the exit face **44** concentric with the aperture stop **10** as shown in FIG. **1A**, the rear exit face **54** will be optically concentric with the aperture stop **10** also Thus, for example, where the converging ray **34** passes directly through the beamsplitter **40** and impinges on the focal surface **30**, it also is reflected from the partially reflective surface **48** and impinges on a second focal surface **56**. In such a configuration, separate detectors or arrays of detectors can be located at the two separate focal surfaces **30** and **56** for viewing a common scene.

Where more than two focal planes or surfaces are desired, a beamsplitter **40'** such as shown in FIG. **3** may be utilized. There, three pentagonal beamsplitter segments **58**, **60** and **62** are bonded together along mutually opposing faces **64** and **66**. The left segment **58** as shown in FIG. **3** includes a partially reflective buried surface **48** intermediate a direct output face **44** and a rearwardly facing exit face **54** as in FIG. **2**. The relatively large middle segment **60**, in addition to having a pair of longitudinal sides faces **68** and **70**, also includes the convex entrance face **42** as in FIG. **2**. A second partially reflective buried surface **72** is angularly disposed between the entrance face **42** and acts to reflect the impinging converging beam **34** back into the right segment **62** which has a pair of concave exit faces **74** and **76** located on opposite sides of a third partially reflective buried surface **78** extending between the side faces **80** and **82**.

It can be seen that the converging beam **34** reflected from the partially reflective surface **72** is directed to the partially reflective surface **78** where it leaves at the exit face **74** to impinge on the focal surface **84**; however, a portion of the light energy is reflected from the partially reflective surface **78** where it leaves the exit face **76** and impinges on the focal surface **86**.

The entrance face **42** and the exit face **44** are not only optically but physically concentric to the aperture stop; however, the exit faces **54**, **74** and **76** are optically concentric to the aperture stop **10** shown, for example, in FIG. **1A** inasmuch as the exit face **54** coincides with exit face **44** when folded about the partially reflective surface **48**. The curved exit face **74** optically coincides with the exit face **44** when considered to be folded back from the partially reflective surface **72**. And lastly, the fourth curved exit face **76** coincides with exit face **74** when folded back along the partially reflective surface **78**.

When desirable, the beamsplitters **40** and **40'** may be dichroic, i.e. having the property of presenting different colors in two different directions. When all reflective pupil concentric objectives uses, for example, the reflector **12** with a dichroic concentric beamsplitter, the change in refractive index in the beamsplitter will cause a slight change in the focal length as wavelength changes and accordingly a different focal length will be produced for each focal plane. This effect can be compensated for in instances where the bandwidth is small by changing the respective path lengths for the output legs of the beamsplitter. When this is done, the radii of the concave exit faces must also be changed in order to keep them respectively concentric to the aperture stop. This is an important feature of the concentric beamsplitter since it permits the use of an all reflective focusing objective. The limiting aberration in the system then becomes spherochromaticism, that is, a change in the spherical aberration with wavelength. Since the power and spherical aberration of concentric beamsplitters is quite low, systems with a very large range of wavelength are possible without resorting to additional structure for compensation of chromatic aberration.

There are no inherent limits in the number of beam splits possible with the subject invention. The only true limitations are a loss of energy in each split and a restricted amount of space available for the beamsplitters in a system environment. Furthermore, the disclosed

invention provides for implementation of multi-focal planes operative in different wavelengths, for example, over a range from 0.5 micrometers to 12.0 micrometers, in a single optical system.

Having thus shown and described the subject invention in specific detail, the same has been provided by way of explanation and not of limitation and accordingly all modifications, alterations and changes coming within the spirit and scope of the invention are herein meant to be included.

I claim:

1. A pupil concentric optical imaging system comprising:

an aperture stop (10);

an image forming objective including a first optical element (12) concentric with said aperture stop (10) and adapted to converge a light beam (16) impinging thereon from said aperture stop, and

a second optical element (40) situated in the path of said converging beam (34) from said first optical element (12), said second optical element (40) including an entrance face (42) and at least two exit faces (44, 54) from which images emerge to at least two focal surfaces (30, 56), said entrance and exit faces (42, 44, 54) being curved and optically concentric to said aperture stop (10).

2. The apparatus as defined by claim 1 wherein said first optical element (12) includes a curved reflective surface (14) and wherein said entrance face (42) and said exit faces (44, 54) are convexly curved towards said reflective surface (12) whereby a plurality of angularly offset images projected by separate light beams (16, 20, 22) to said aperture stop (10) forms a respective plurality of spatially separated images on said focal surfaces (30, 56).

3. Apparatus for eliminating predetermined optical aberrations generated by a beamsplitter in a pupil concentric optical system comprising:

an aperture stop (10);

at least one image forming objective including at least one light energy converging means (12) concentric with said aperture stop (10) and adapted to converge a light beam (16) impinging thereon from said aperture stop, and

a beamsplitter (40) situated in the path of a converging light beam (34) from said converging means (12), said beamsplitter including an entrance face (42) and at least two exit faces (44, 54) from which respective images emerge, said entrance and exit faces being curved and optically concentric to said aperture stop (10).

4. The apparatus as defined by claim 3 wherein said beamsplitter (40) comprises a buried surface beamsplitting element.

5. The apparatus as defined by claim 4 wherein said curved entrance face (42) has a curvature which is substantially perpendicular to all parts of the field of view of said system.

6. The apparatus as defined by claim 4 wherein said curved entrance and exit faces (42, 44, 54) are generally spherical.

7. The apparatus as defined by claim 4 wherein said converging means (12) comprises a generally spherical reflector.

8. The apparatus as defined by claim 7 wherein said beamsplitter (40) is located intermediate said generally spherical reflector (12) and said aperture stop (10) and wherein said exit faces (44, 54) are generally spherical and concave and said entrance face (42) is generally spherical and convex and directed to said generally spherical reflector (12).

9. The apparatus as defined by claim 8 wherein the spherical curvature of said entrance face (42) substantially matches the spherical curvature of the face (14) of said reflector (12).

10. The apparatus as defined by claim 4 wherein said buried surface beamsplitting element (40) includes at least one partially reflective interior surface (48) angularly oriented with respect to the said structure face (42) and wherein said exit faces (44, 54) are located on each side of said partially reflective interior surface (48).

11. The apparatus as defined by claim 3 wherein said beamsplitter (40) further comprises a buried surface beamsplitter (40') including a plurality of exit faces (44, 54, 74, 76), each of said exit faces being respectively optically concentric to the aperture stop (10) and forming thereby a respective plurality of images of said light beam (16) on different focal surfaces (30, 56, 84, 86).

12. The apparatus as defined by claim 11 wherein said buried surface beamsplitter (40') includes a plurality of partially reflective interior surfaces (48, 72, 78) angularly oriented with respect to said entrance free (42) and wherein a respective exit face of said plurality of exit faces (44, 54, 74, 76) is located on each side of said plurality of partially reflective interior surfaces (48, 72, 78).

13. The apparatus as defined by claim 12 wherein said beamsplitter (40') is comprised of a plurality of pentagonal segments (58, 60, 62), each of said segments having a respective partially reflective buried interior surface (48, 72, 78).

14. The apparatus as defined by claim 4 and additionally including corrector plate means (32) located at said aperture stop (10).

15. The apparatus as defined by claim 4 wherein said beamsplitter (40, 40') is dichroic.

16. The apparatus as defined by claim 15 wherein said dichroic beamsplitter (40, 40') includes path lengths for the output legs which are compensated for wavelength changes of said light beam.

17. The apparatus as defined by claim 15 wherein said dichroic beamsplitter (40, 40') includes exit faces (44, 54, 74, 76) which are generally spherical and having radii which compensate for wavelength changes of said light beam.

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